Atlantic Oceanographic and Meteorological Laboratory

The Impact of Quantitative Satellite Data on Numerical Weather Prediction

Robert Atlas

NASA Earth Science at 20 Symposium
June 22, 2009

Impact of satellite temperature soundings during the Data Systems Tests (DST)

- **NASA Studies**: Halem et al. (1978), Ghil et al. (1979a,b), Atlas et al. (1979, 1982), Atlas (1979, 1982)
- **NOAA/NMC Studies:** Desmaris et al. (1978), Tracton et al. (1980, 1981)
- NMC acknowledged significant beneficial impact at AMS NWP conf. in 1979 and in later papers.

Time-Continuous Assimilation of Remote-Sounding Data and Its Effect on Weather Forecasting

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(Manuscript received 7 April 1978, in final form 6 October 1978)

ABSTRACT

Methods are derived for the time-continuous four-dimensional assimilation of satellite sounding temperatures. The methods presented include time-continuous versions of direct insertion, successive correction and statistical linear regression. They are applied to temperature sounding data obtained from radiance measurements taken by instruments aboard the polar-orbiting satellites NOAA 4 and Nimbus 6. The data were collected during the U.S. Data System Test in January–March 1976.

A comprehensive series of experiments was performed to study the effects of using various amounts of satellite data and differing methods of assimilation. The experiments included the assimilation of data from the NOAA 4 satellite only, from Nimbus 6 only, and of data from both satellites combined. Other experiments involved variations in the application of our time-continuous statistical assimilation methods and of asynoptic successive correction methods. Intermittent assimilation of the sounding data was also tested, and its results compared with those of time-continuous assimilation.

Atmospheric states determined in the assimilation experiments served as initial states for a sequence of evenly spaced 3-day numerical weather forecasts corresponding to each experiment. The effects of the satellite data were evaluated according to the following criteria: 1) differences between the initial states produced with and without utilization of satellite data, 2) differences between numerical predictions made from these initial states, and 3) differences in local weather forecasts resulting from the large-scale numerical predictions.

Initial-state differences were evaluated in terms of magnitude and location of large-scale differences between meteorological fields. Numerical prediction differences were evaluated in terms of S_1 skill scores and rms errors, as well as by synoptic case studies. An automated forecasting model (AFM) based on quasi-geostrophic theory and on subjective forecasting principles was developed to facilitate the objective evaluation of differences produced in local weather forecasts, especially precipitation forecasts.

These studies suggest the following conclusions: 1) satellite-derived temperature data can have a modest, but statistically significant positive impact on numerical weather prediction in the 2–3 day range; 2) the impact is highly sensitive to the quantity of data available, and increases with data quantity; and 3) the method used to assimilate the satellite data can influence appreciably the magnitude of the impact obtained for the same data.

The Impact of Satellite Soundings on the National Meteorological Center's Analysis and Forecast System—The Data Systems Test Results

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(Manuscript received 29 January 1979, in final form 28 December 1979)

ABSTRACT

In order to assess the value of remote sounding data for numerical weather prediction, parallel sets of analyses were produced with (SAT) and without (NOSAT) the sounding data from the experimental Nimbus-6 and operational NOAA-4 satellites for the Data Systems Test periods, 18 August–4 September 1975 (DST-5), and 1 February–4 March 1976 (DST-6). All other factors, i.e., the assimilation method and remainder of the data base, were identical for both the SAT and NOSAT modes of each set. For selected days of DST-5 and DST-6, forecasts were generated through 72 h over the Northern Hemisphere. Differences between corresponding SAT and NOSAT analyses and the forecasts produced therefrom were assessed via a set of objective and subjective procedures, including evaluation of standard skill scores and judgment by experienced meteorologists.

The effect of remote temperature soundings in the NMC DST experiments was generally small and of inconsistent sign, i.e., beneficial in some cases, harmful in others. The average of these positive and negative contributions over the cases considered proved slightly positive for the DST-6 period and slightly negative for the DST-5 period. Neither result was judged of much meteorological consequence. Overall, we conclude that the remote soundings had little impact on forecasts in the Northern Hemisphere.

However, systematic differences were noted between the SAT and NOSAT analyses—the amplitude of weather systems was consistently less in the SAT mode. The reduced amplitude reflected an intrinsic characteristic of the remote soundings; *viz.*, the tendency for the satellite temperature retrievals to underestimate the spatial variance in the thermal structure of the atmosphere.

The Effect of Model Resolution and Satellite Sounding Data on GLAS Model Forecasts

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(Manuscript received 15 April 1981, in final form 11 March 1982)

ABSTRACT

An experiment was performed to study the effect of increased model resolution on satellite sounding data impact. Assimilation cycles were carried out with data from 0000 GMT 29 January to 0300 GMT 21 February 1976, using coarse- and fine-resolution versions of the GLAS second-order general circulation model (GCM). For each model resolution, an assimilation cycle was performed using both conventional and experimental data, which included temperature soundings from the NOAA-4 and Nimbus-6 satellites. A second cycle was run using the same data but excluding the satellite-derived temperature soundings.

The objective analyses produced by the assimilation cycles were used as initial states for a series of evenly spaced 72 h numerical weather forecasts. Eleven forecasts with the same resolution in the forecast model as in the data assimilation were performed at 48 h intervals for each assimilation. Additional forecasts were made with the higher resolution forecast model from the lower resolution assimilation cycle and vice versa. Initial state differences were evaluated in terms of the magnitude, location and structure of large-scale differences between meteorological fields. Numerical prediction differences were evaluated by means of objective scores and subjective comparisons.

Objective scores show a substantially larger beneficial impact of the sounding data at 48 and 60 h with the higher resolution version of the model. Subjective evaluation also revealed a larger positive impact of satellite sounding data with the higher resolution model.

This study has two important limitations: it was carried out with two versions of one model, the GLAS GCM, and the number of forecast cases analyzed is small. Within these limitations, our results indicate that model improvement enhances the impact of satellite data.

NOTES AND CORRESPONDENCE

The Growth of Prognostic Differences Between GLAS Model Forecasts from SAT and NOSAT Initial Conditions

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15 April 1981 and 11 March 1982

ABSTRACT

A study of the evolution of sounding data impact in the high-resolution GLAS model forecasts from 19 February 1976 has been conducted. The significant prognostic differences which develop in this case are shown to be traceable to specific initial state differences which resulted from the assimilation of satellite-derived temperature soundings.

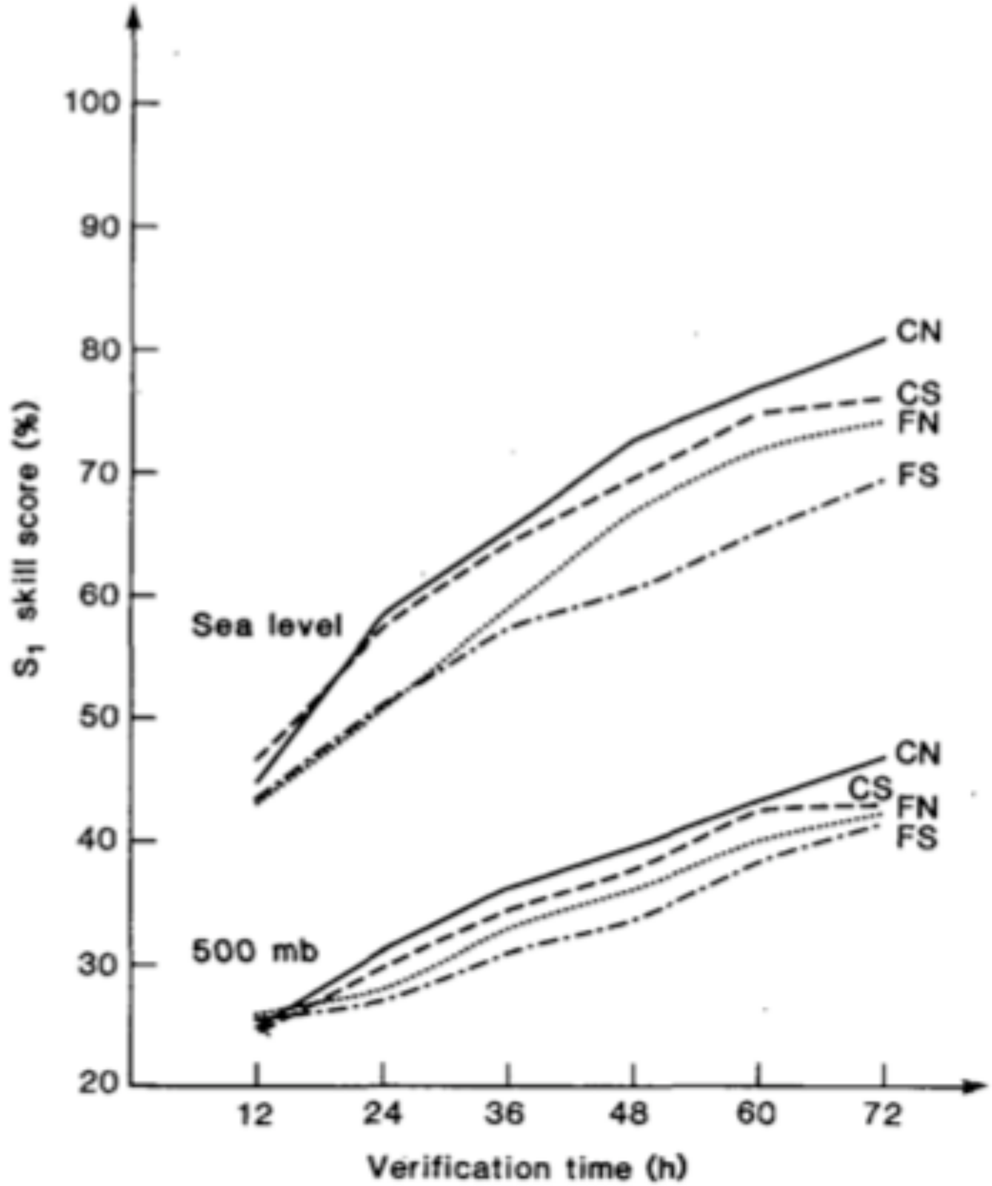
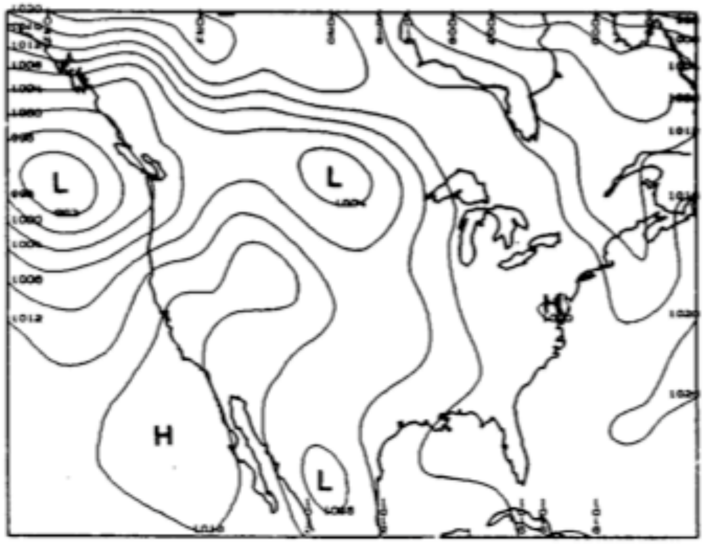


FIG. 3. S_1 score verification of sea-level pressure (upper curves) and 500 mb geopotential height (lower curves) forecasts for North America, averaged over 11 forecasts. Results are presented for the coarse NOSAT (CN), coarse SAT (CS), fine NOSAT (FN) and fine SAT (FS) at 12 h intervals.



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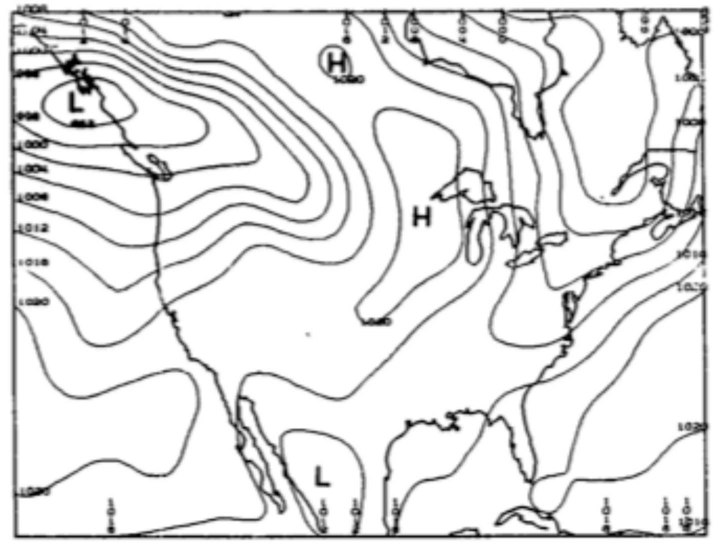

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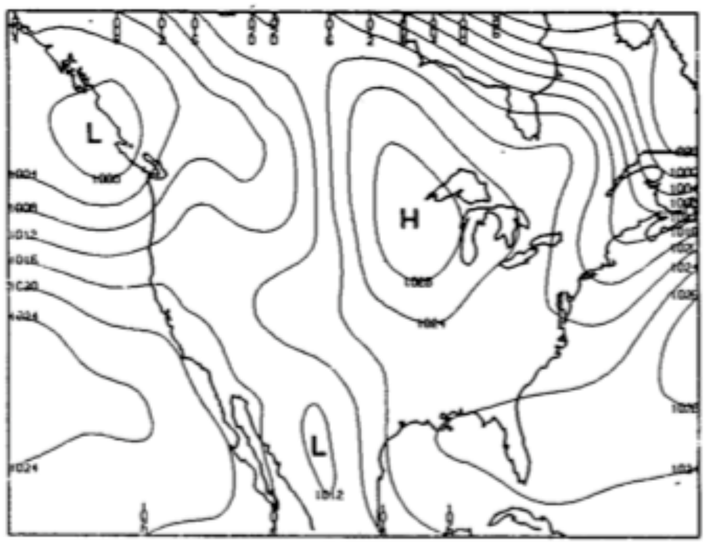

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FIG. 5. The sea-level pressure fields on 0000 GMT 14 February 1976: (a) the 72 h forecast from the coarse-model with NOSAT initial conditions (CN); (b) the corresponding SAT forecast using the coarse-model (CS); (c) the corresponding NOSAT forecast using the fine-model (FN); (d) the corresponding SAT forecast using the fine-model (FS); (e) the verifying NMC analysis.

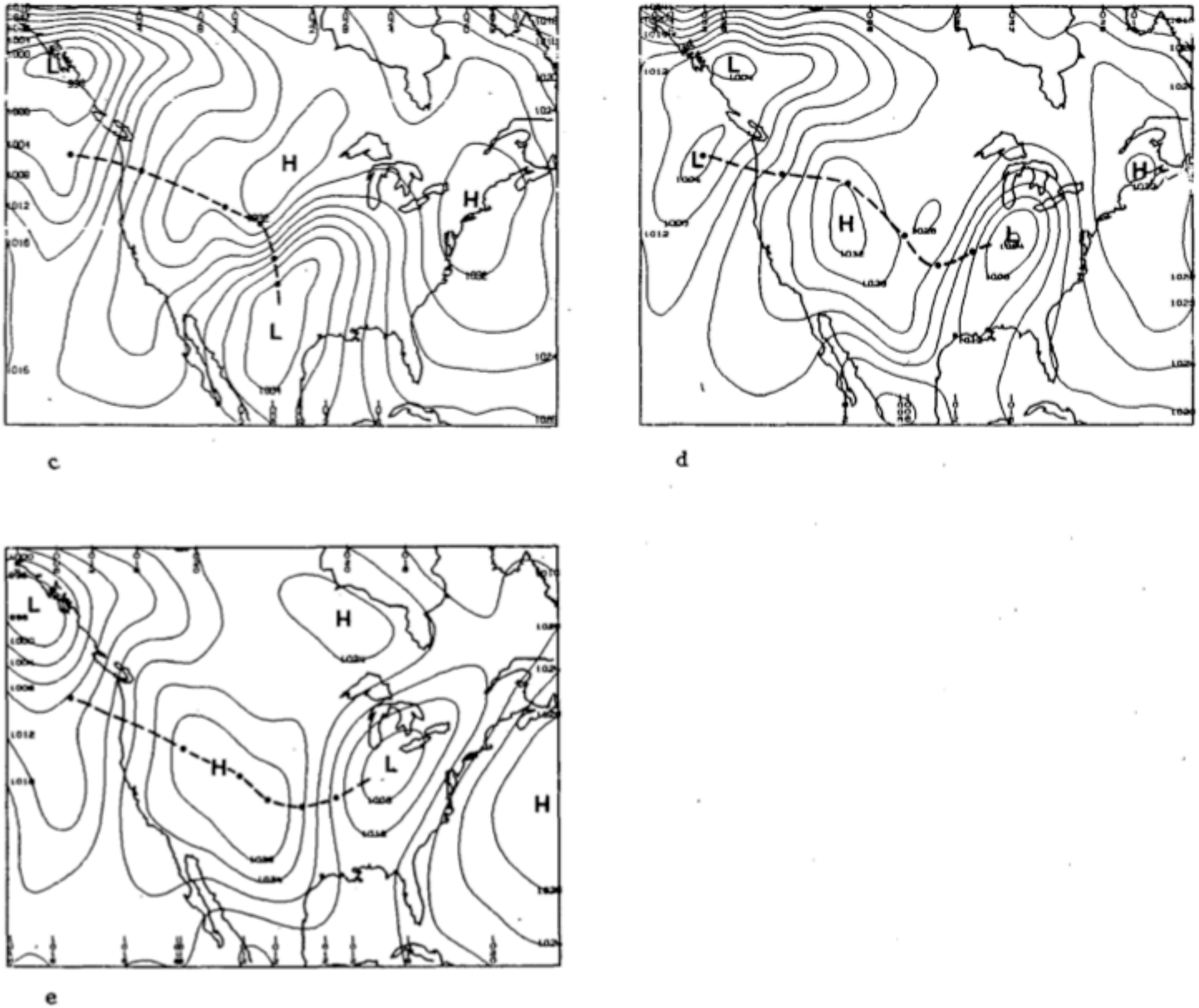


FIG. 4. The sea level pressure fields on 0000 GMT 22 February 1976: (a) the 3-day forecast from the coarse-model with NOSAT initial conditions (CN); (b) the corresponding SAT forecast using the coarse-model (CS); (c) the corresponding NOSAT forecast using the fine-model (FN); (d) the corresponding SAT forecast using the fine-model (FS); (e) the verifying NMC analysis. Dots represent past positions of the cyclone center at 12 h intervals beginning 0000 GMT 19 February 1976.

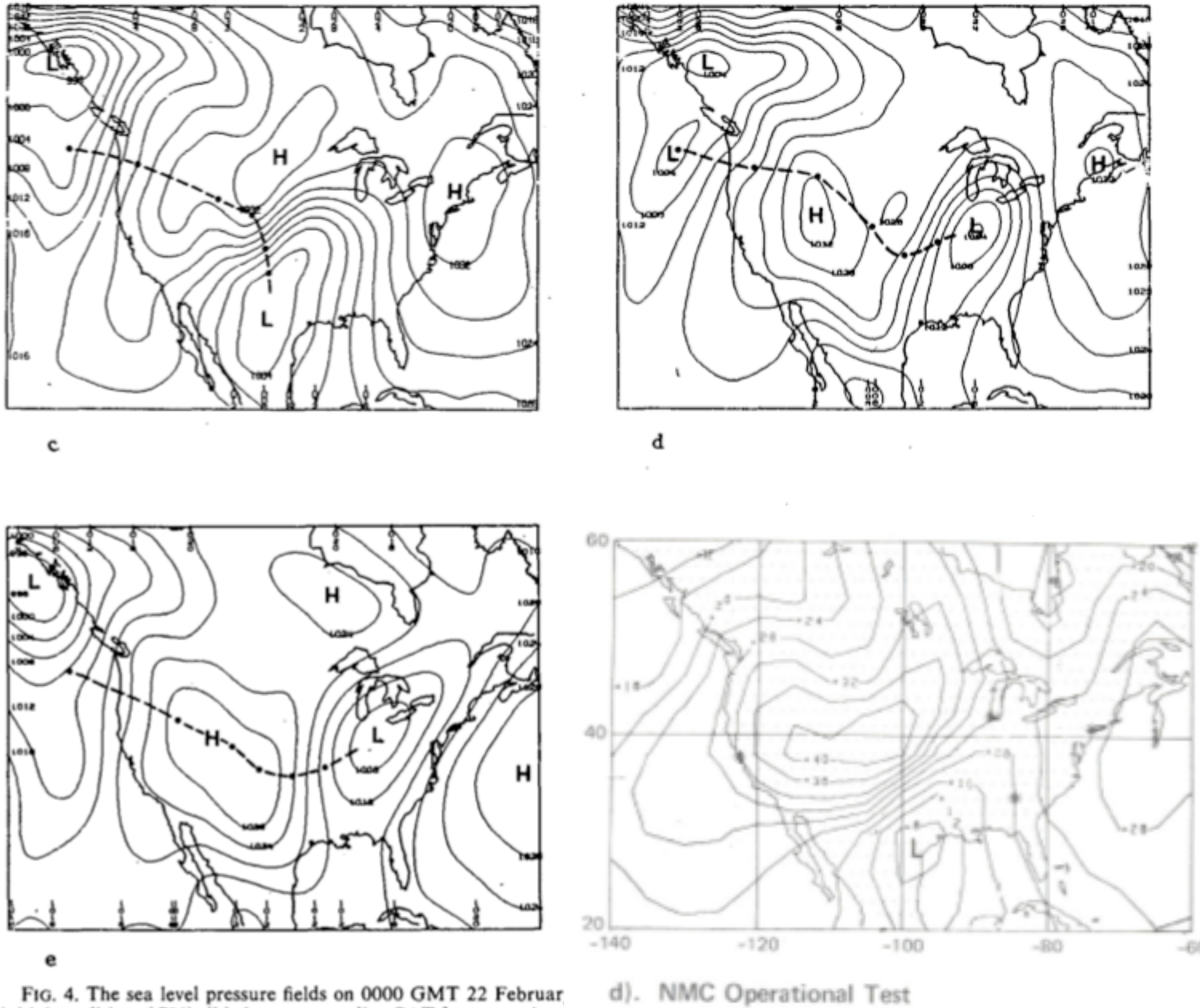


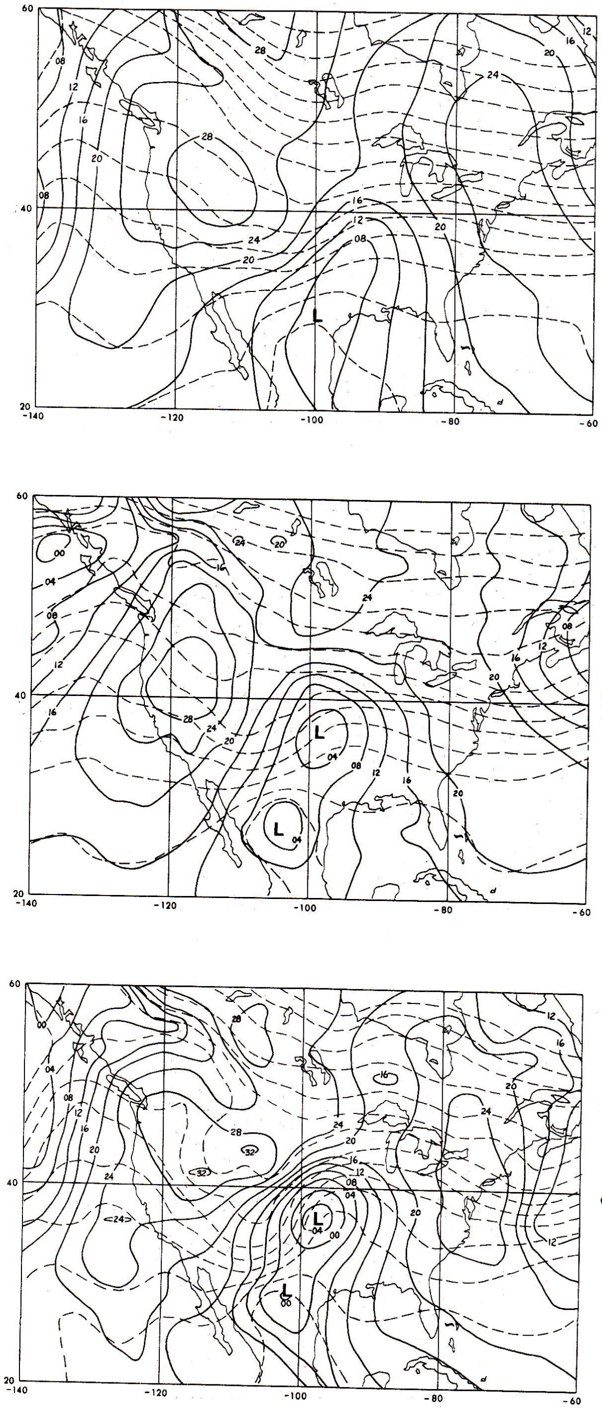
FIG. 4. The sea level pressure fields on 0000 GMT 22 Februar initial conditions (CN); (b) the corresponding SAT forecast using the fine-model (FN); (d) the corresponding SAT forecast using the fine-model (FS); (e) the verifying NMC analysis. Dots represent past positions of the cyclone center at 12 h intervals beginning 0000 GMT 19 February 1976.

NASA

Technical Memorandum 80591

A Comparison of GLAS SAT and NMC High Resolution NOSAT Forecasts From 19 and 11 February 1976

Robert Atlas

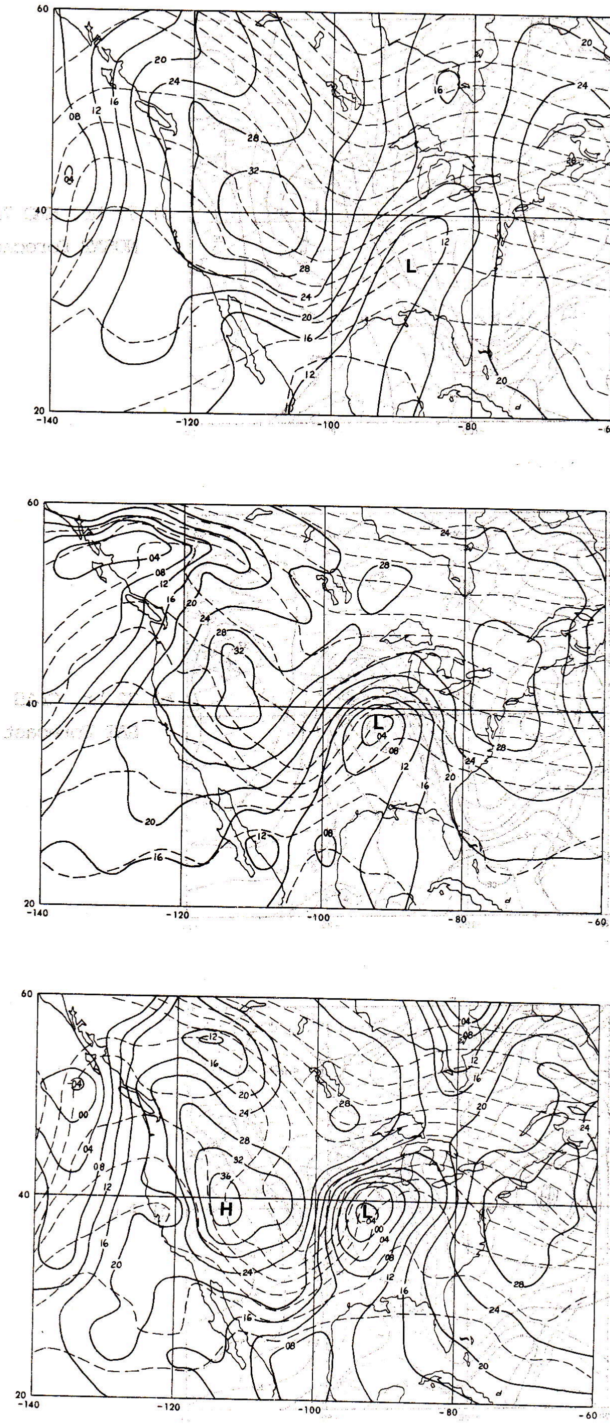


a) 48 hr. NMC 7I
NOSAT Forecas

b) 48 hr. GLAS
SAT Forecast

c) Analysis

Fig. 4. Sea level pressure/1000-500 mb thickness maps for 0000 GMT 21 Feb. 1976

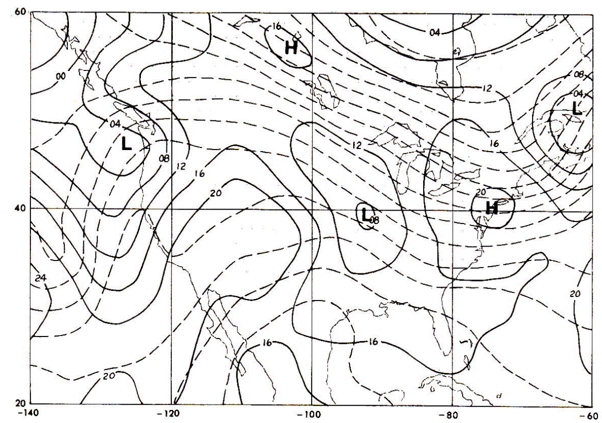


a) 60 hr. NMC 7L
NOSAT Forecast

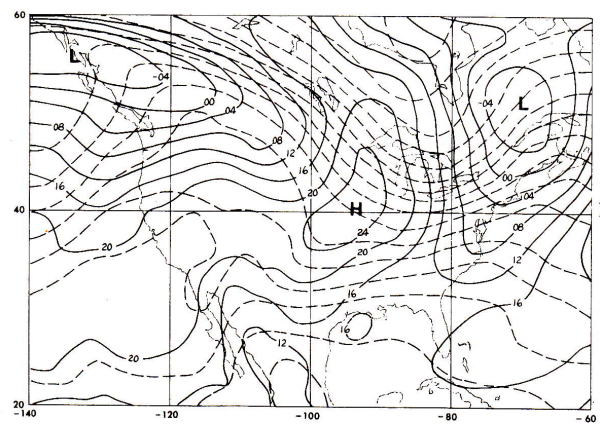
b) 60 hr. GLAS
SAT Forecast

c) Analysis

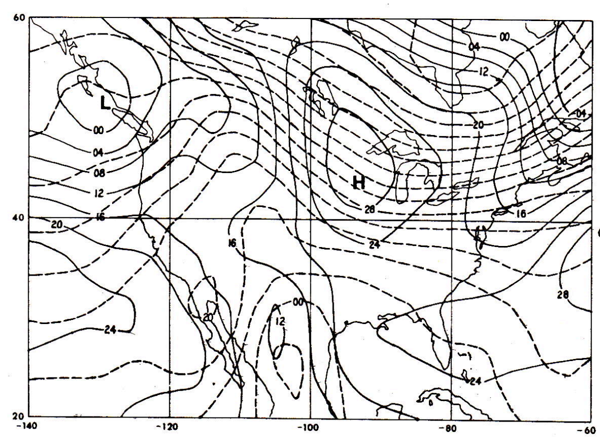
Fig. 5. Sea level pressure/1000-500 mb thi



a) 72 hr. NMC 7L NOSAT Forecast



b) 72 hr. GLAS SAT Forecast



c) Analysis

Fig. 9. Sea level pressure/1000-500 mb thickness maps for 0000 GMT 14 Feb. 1976.

On the System Dependency of Satellite Sounding Impact—Comments on Recent Impact Test Results

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4 March 1980 and 3 July 1980

ABSTRACT

As shown by the Data Systems Test results, the impact of satellite temperature soundings on numerical weather prediction is highly dependent on the particular analysis and forecast system used to incorporate the data. The more amenable a system is to improvements, the greater the potential for the satellite observations to produce a beneficial effect.

yses. An improved version of the GLAS system has been applied recently to demonstrate two cases (11 and 19 February 1976) for which positive impact was obtained and the GLAS system outperformed that of NMC (Atlas, 1979). We are delighted that two cases of undisputed positive impact have been identified.

Impact of current and future satellites

- Impact of current instruments
  - SeaWinds on Quikscat,
  - TRMM, AIRS, MISR, MODIS

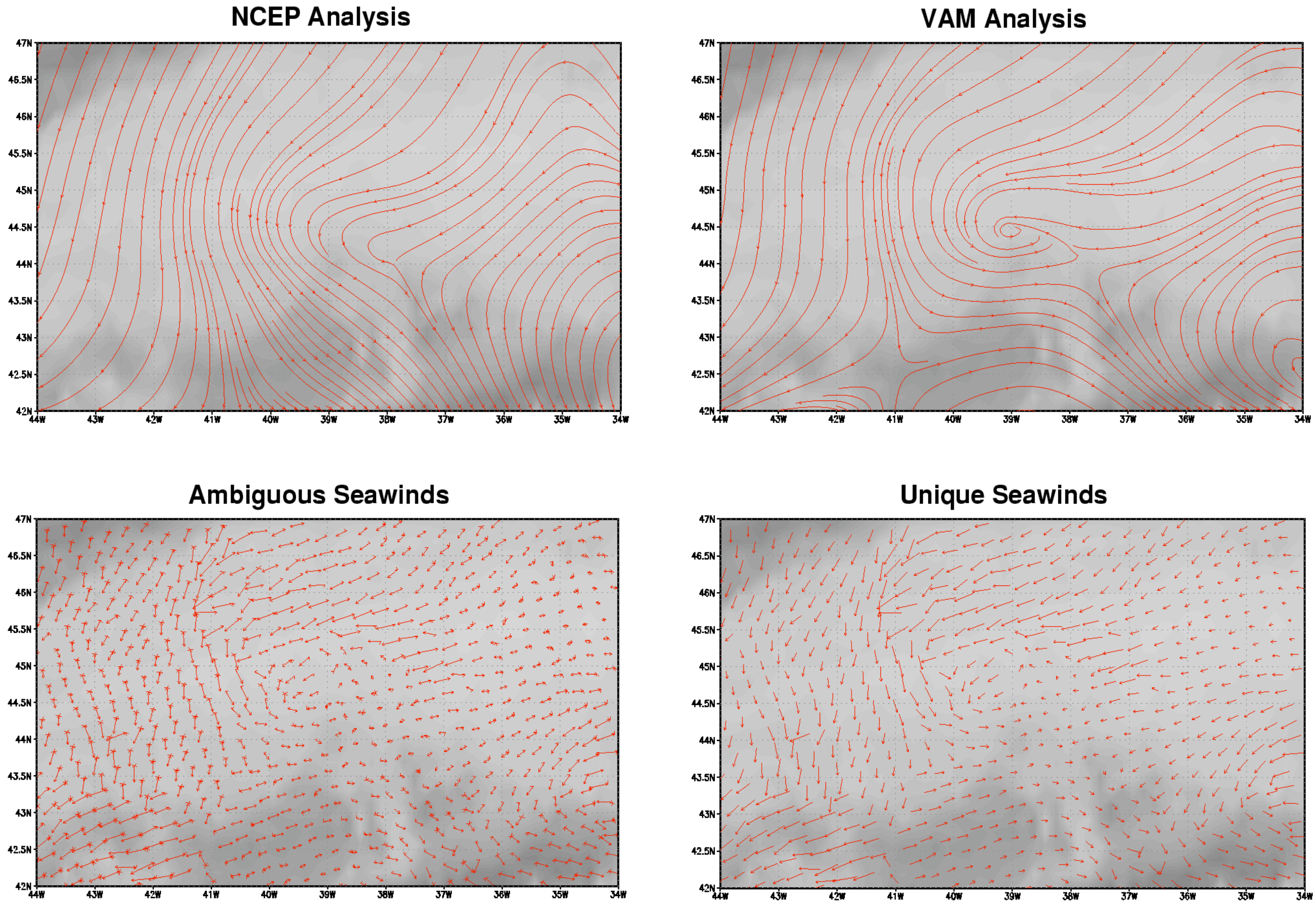
- New instruments and their potential
  - Doppler Wind Lidar
  - XOVWM or Dual Frequency Scatterometer
  - Aries
  - PATH

Impact of SeaWinds Scatterometer Data on Ocean

Surface Analysis and Weather Prediction

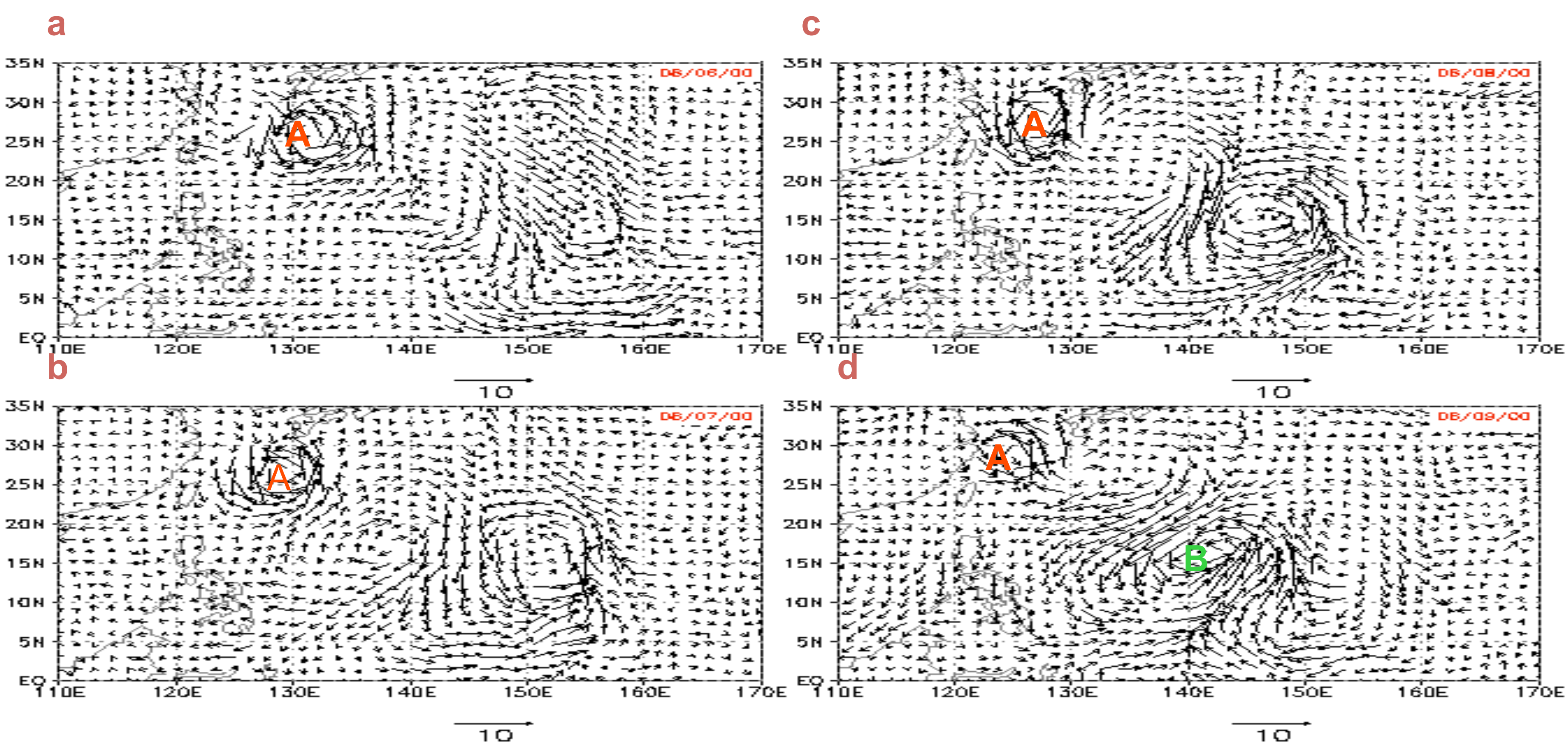
Example of a Cyclone Added by Seawinds in the North Atlantic

(shaded field represents clouds from GOES East IR4)



April 11 2003 00Z

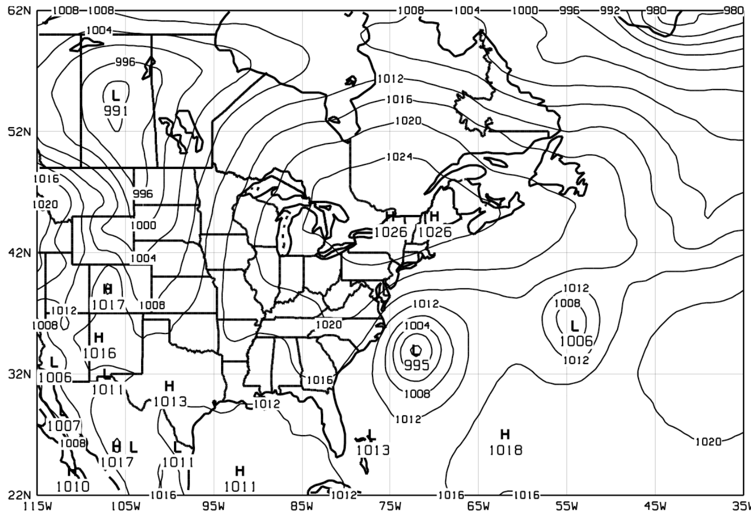
Detecting the Birth of Tropical Storms



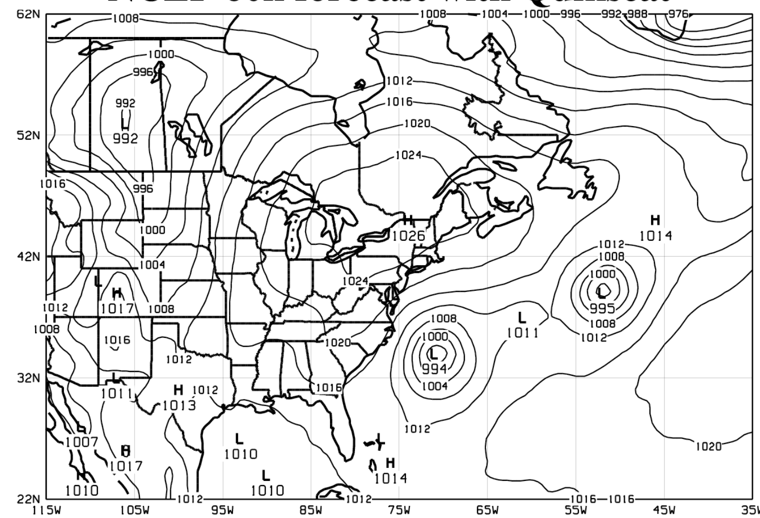
Using QuikSCAT surface wind data from 2000-2001, Li et al. identified various processes by which tropical cyclones (TC) are formed in the western North Pacific.

Example of Hurricane Forecasting

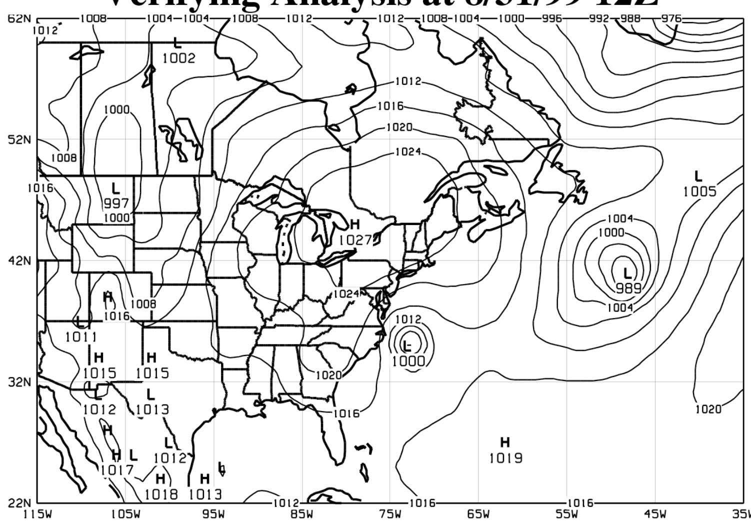
NCEP 60h forecast w/o Quikscat



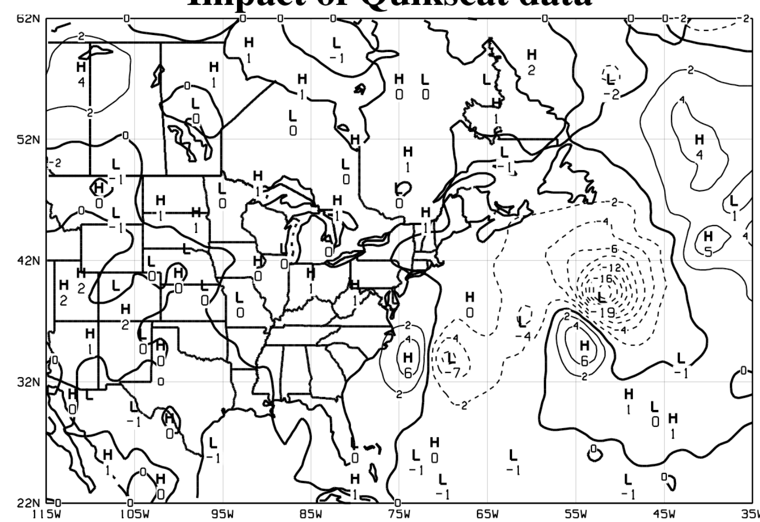
NCEP 60h forecast with Quikscat



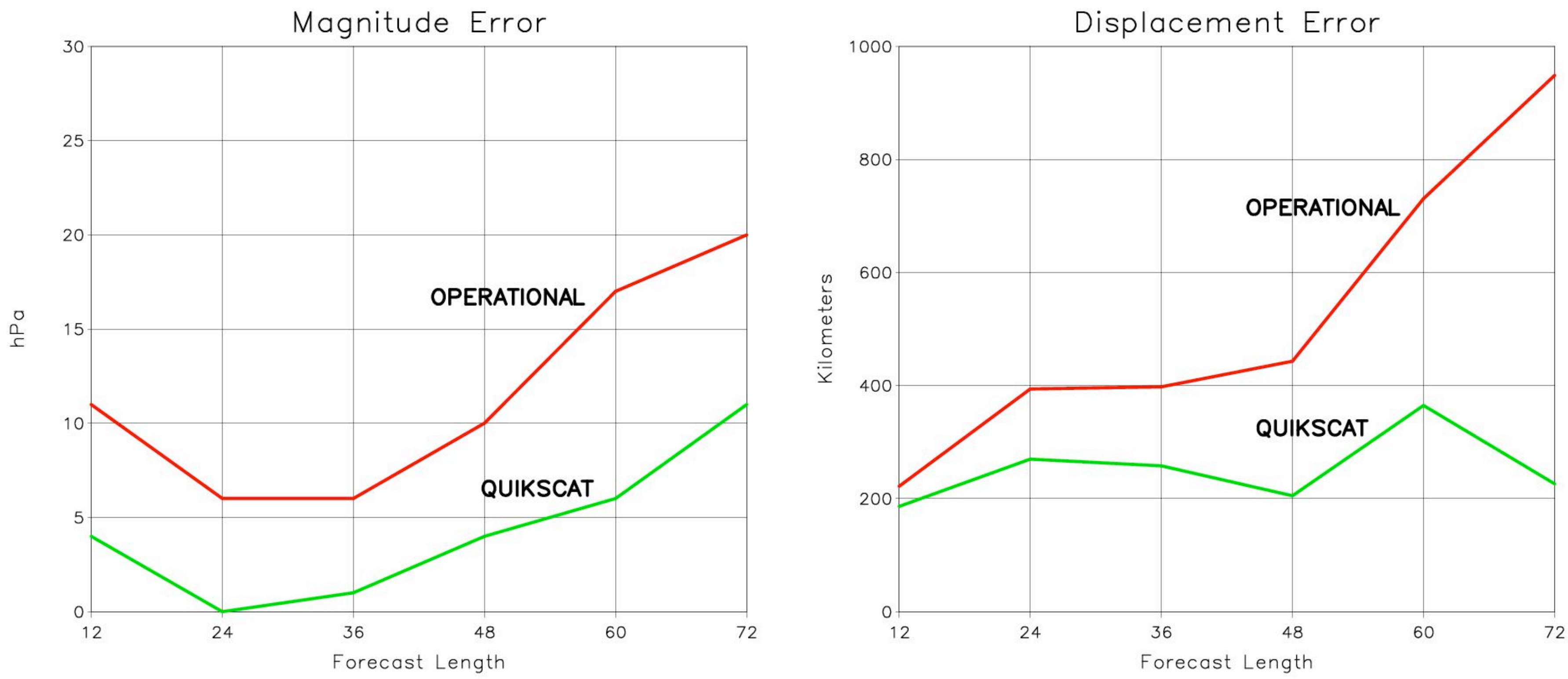
Verifying Analysis at 8/31/99 12Z



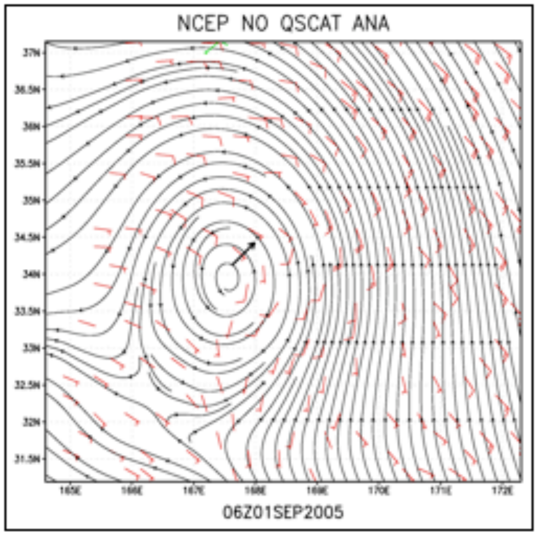
Impact of Quikscat data

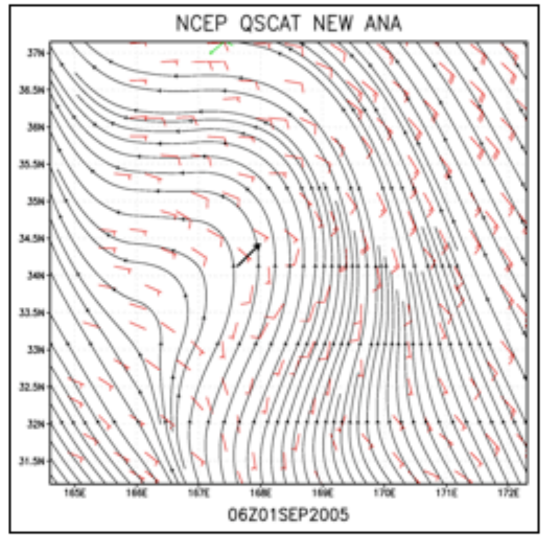


Prediction of Hurricane Cindy using QuikScat Data



Analysis	Cyclones Added	Cyclones Deleted	Position Impact Avg (km)	Max	Vorticity Impact Avg	Max	Max Wind Impact Avg (m/s)	Max
NCEP	155	346	89	186	-0.4	2.4	0.5	2.4
GEOS-5	309	379	100	251	0.1	4.5	0.7	3.0





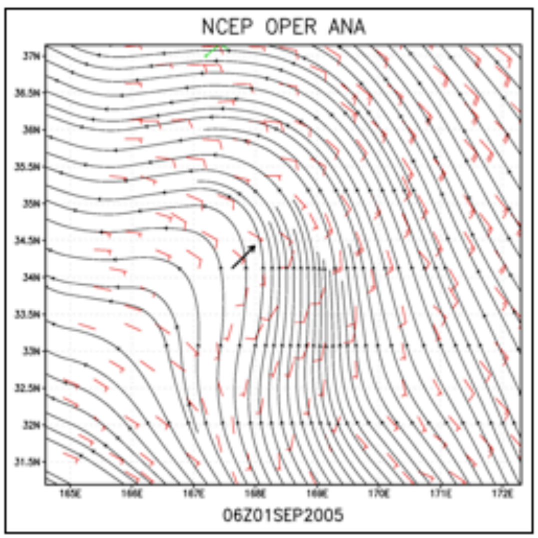


Figure 12 NCEP 1000mb wind analysis on September 1, 2005 6Z. The top left panel shows the NCEP Control analysis (no Quikscat) depicting a closed circulation center (located at the endpoint of the vector marker). Quikscat wind barbs (red) are show for reference. The top right panel shows the 1000mb wind analysis for the NCEP analysis that assimilated the Quikscat winds. The NCEP operational analysis (bottom left) is shown for comparison. In general, the assimilation of Quikscat in the NCEP DAS results in many more deleted cyclones than added as can be seen in this example.

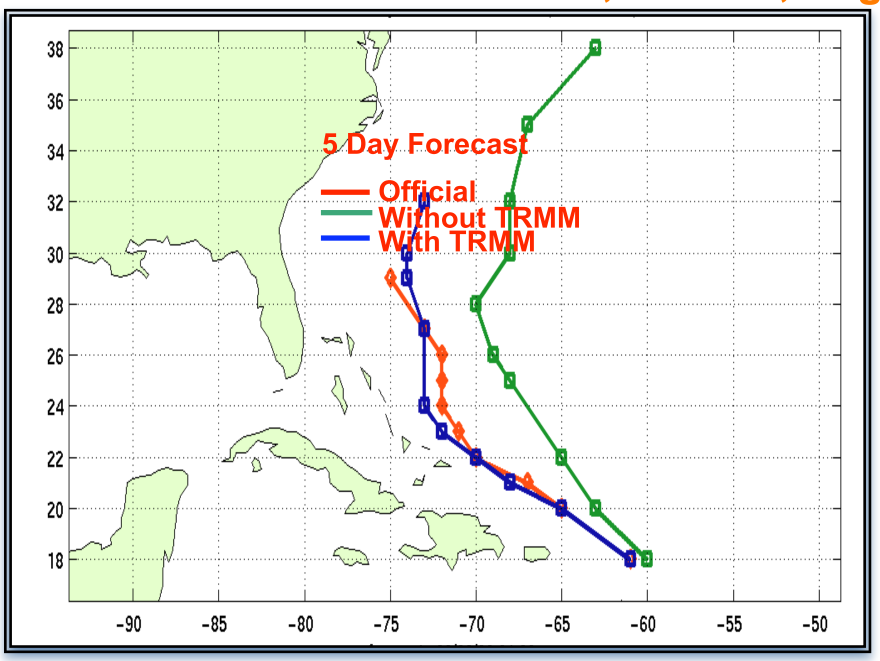
Operational Use and Impacts of TRMM Instruments at NCEP

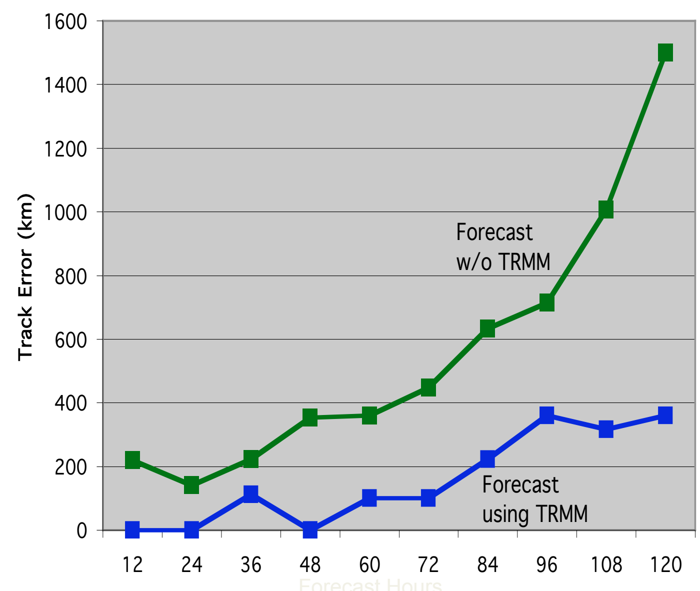
– Real-time estimate of Hurricane intensity and structure (TPC)
– Routine precipitation product
– Input to global data assimilation for model initial conditions

Improving Tropical Cyclone Track Forecasts

Assimilation of TRMM rainfall location, intensity and vertical structure into hurricane forecast models leads to improvements in forecasts of future position

Hurricane Bonnie, Atlantic, Aug 1998





Dr. A. Hou, NASA DAO

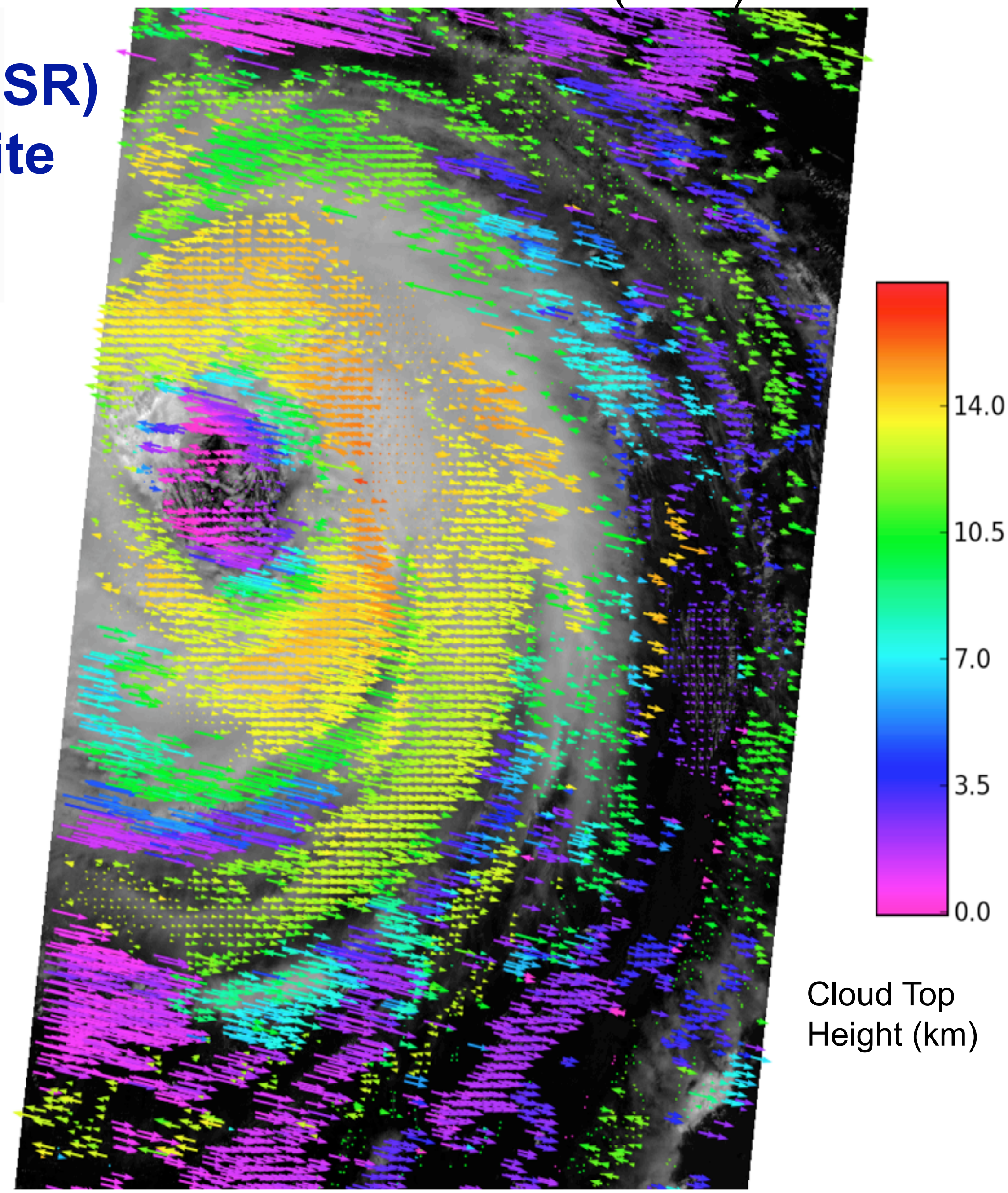
Reduced track errors can save money ($600K - $1M per mile of coast evacuated) and save lives by more precise prediction of eye location at landfall

Multiangle Imaging SpectroRadiometer (MISR) on NASA's Terra Satellite

High Resolution Cross-Track Winds

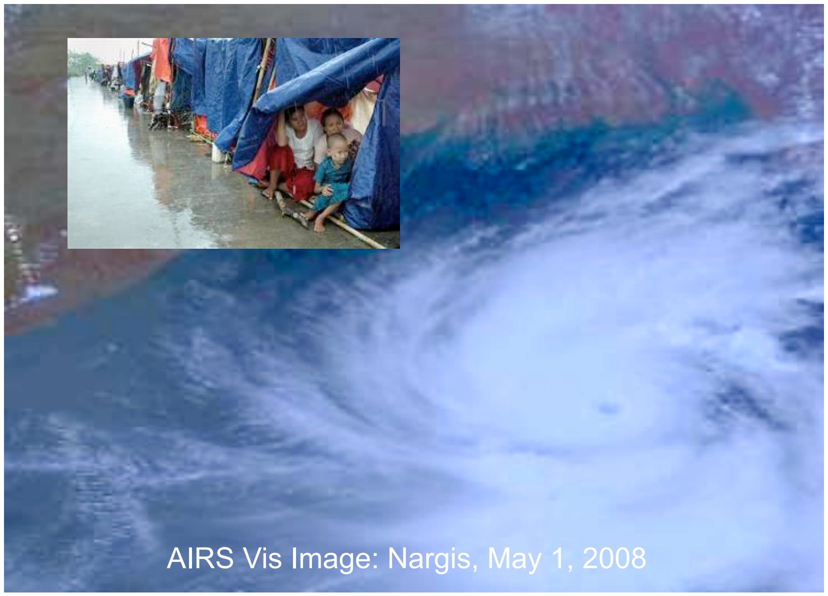
- •Data available from 2000 to present
- •Purely geometric retrieval, model independent
- •Spatial Resolution (1.1 km)
- •Height Resolution (< 500 m)
- •Accuracy (2-3 m/s)
- •Detailed rotation structures inside the eyewall
- •Potential useful for hurricane intensity studies

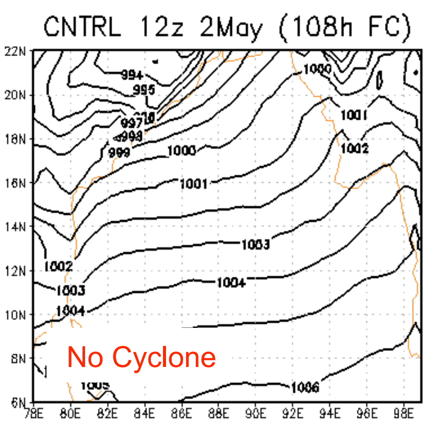
Hurricane Alberto (2000)

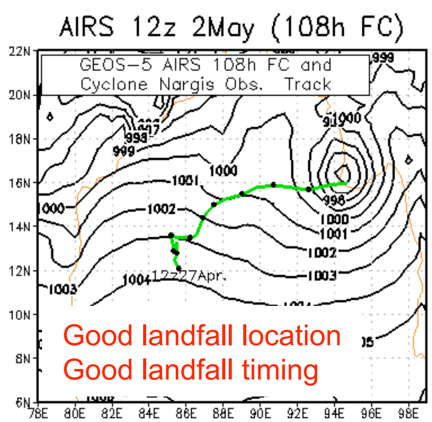


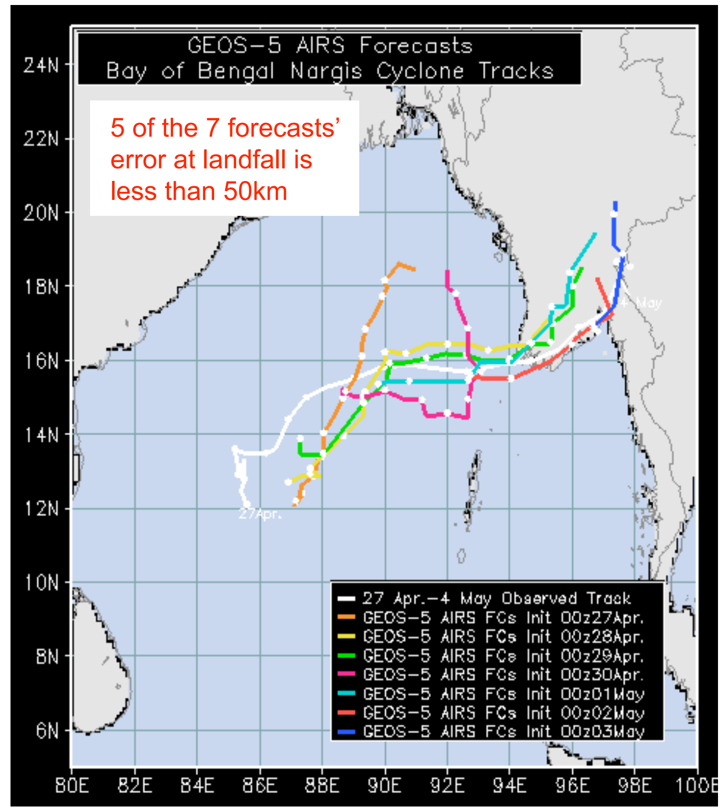
AIRS Improves Tropical Cyclone Forecast

Recent Paper finds AIRS Has Major Impact to Tropical Cyclone Nargis Forecast in Re-Analysis (After Event)





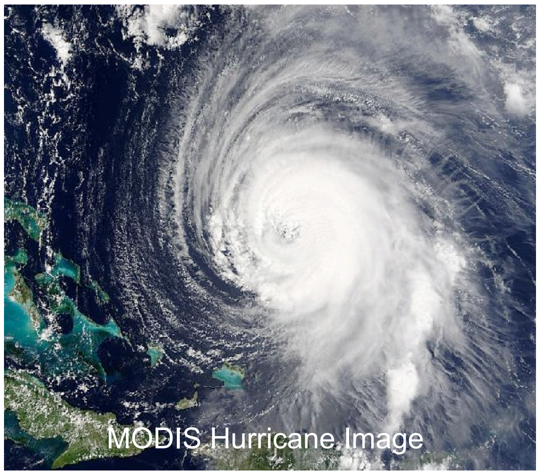




Reale, O., W. K. Lau, J. Susskind, E. Brin, E. Liu, L. P. Riishojgaard, M. Fuentes, and R. Rosenberg (2009), AIRS impact on the analysis and forecast track of tropical cyclone Nargis in a global data assimilation and forecasting system, Geophys. Res. Lett., 36, L06812, doi: 10.1029/2008GL037122.
http://www.agu.org/journals/gl/gl0906/2008GL037122/

Advanced Sounder (ARIES)
High Spatial / High Spectral Resolution

MODIS Spatial Resolution



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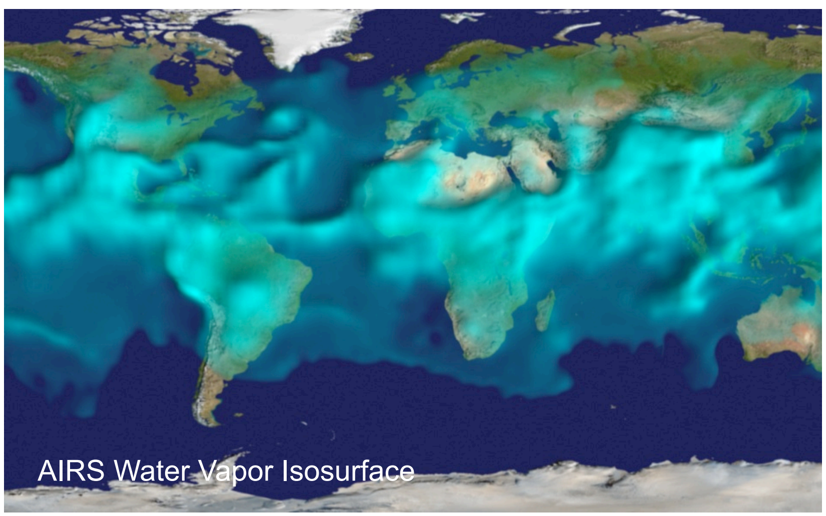
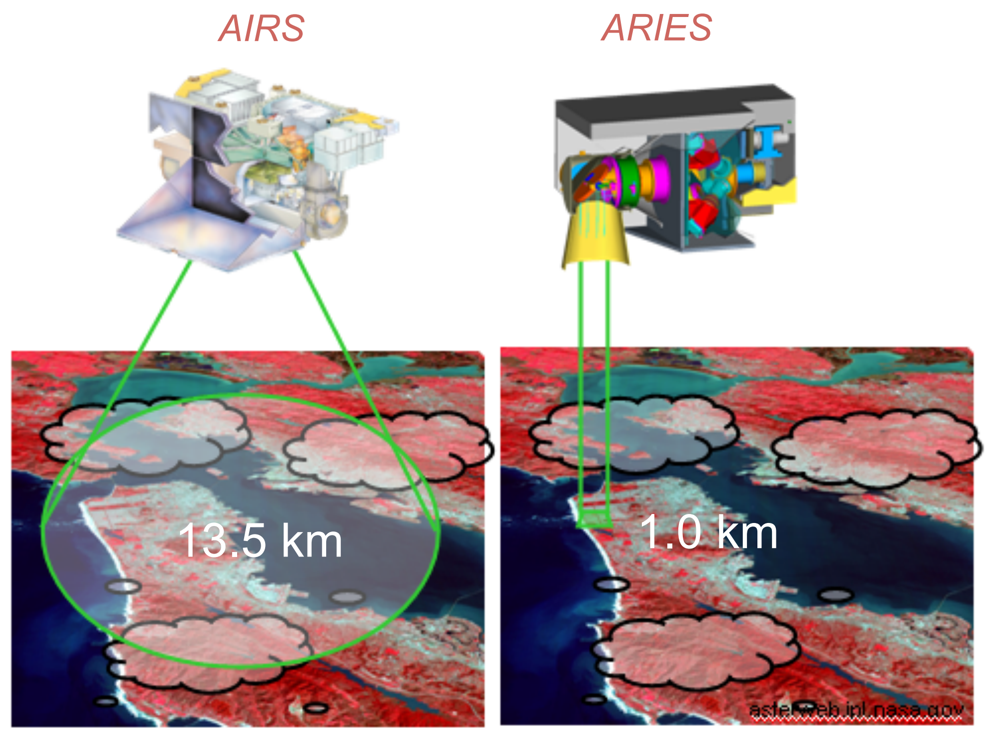
AIRS Spectral Resolution

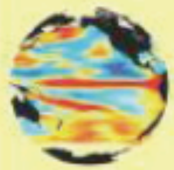




Band	Spectral Range	Spectral Resolution	No. Channels
MW1	2100 - 2950 cm^{-1}	1.0 cm^{-1}	787
MW2	1150 - 1613 cm^{-1}	0.5 cm^{-1}	1000
LW1	880 - 1150 cm^{-1}	0.5 cm^{-1}	637
LW2	650 - 880 cm^{-1}	0.4 cm^{-1}	674

Decadal Survey Mission	Mission Description	Orbit	Instruments	Rough Cost Estimate
Timeframe 2010 – 2013, Missions listed by cost				
CLARREO (NASA portion)	Solar radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer	$200 M
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer	$300 M
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter	$300 M
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter	$700 M
Timeframe: 2013 – 2016, Missions listed by cost				
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer	$300 M
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser	$400 M
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar	$450 M
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers	$550 M
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar	$800 M
Timeframe: 2016 -2020, Missions listed by cost				
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter	$300 M
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST	GEO	MW array spectrometer	$450 M
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system	$450 M
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers	$500 M
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	$600 M
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	$650 M

Precipitation and All-weather Temperature and Humidity (PATH)
Launch: 2016-2020
Mission Size: Medium



Sea surface temperature

Temperature and humidity profiles

Constraints on models for boundary layer, cloud, and precipitation processes

More accurate, longer-term weather forecasts

Improved storm track and intensification prediction and evacuation planning

Determination of geographic distribution and magnitude of storm surge and rain accumulation

PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST[a]	GEO	MW array spectrometer	$450 M

= GeoSTAR!

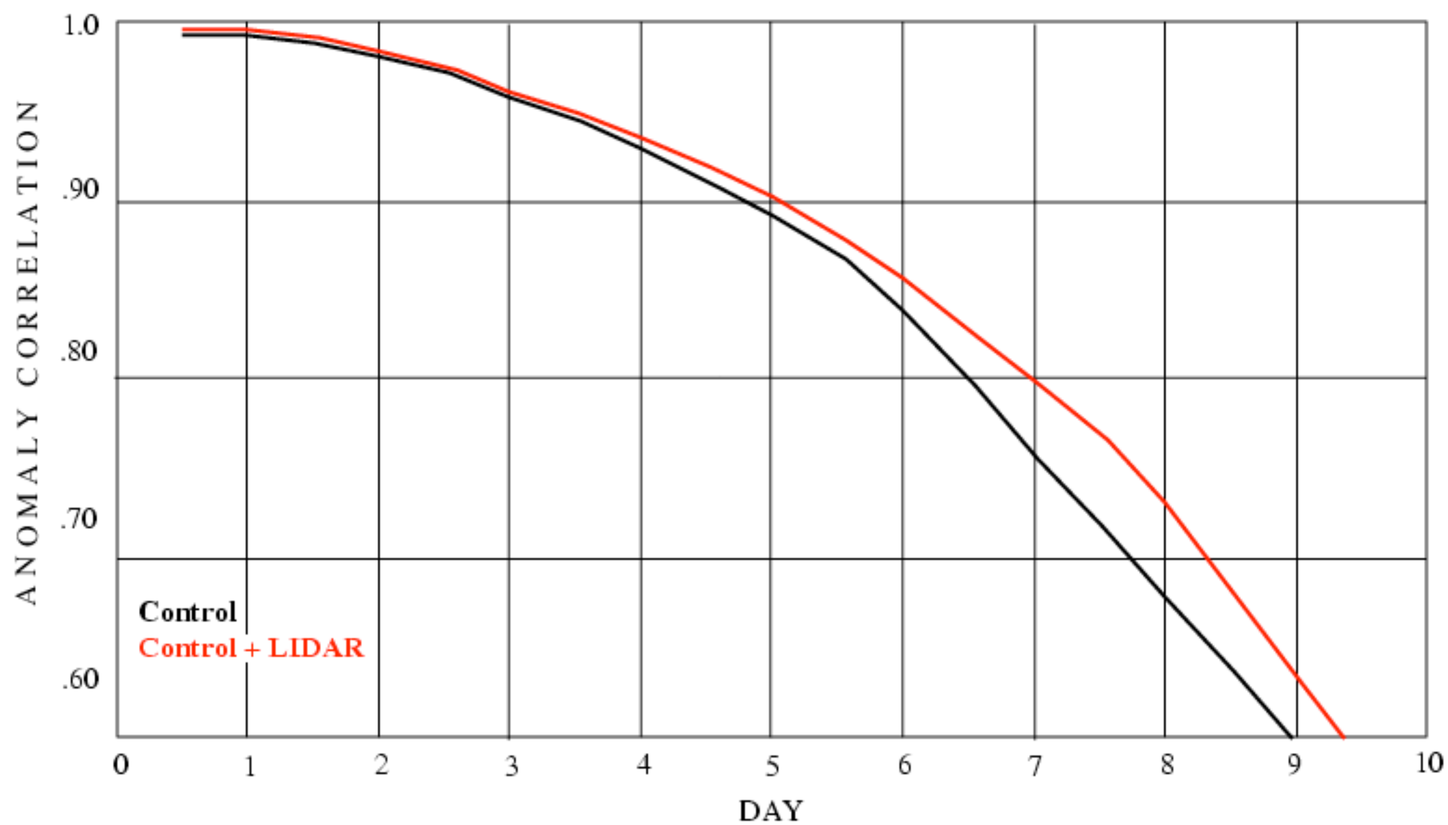
Note: The NRC panel put PATH in the 3rd group, reflecting their perception of the maturity of the required technology
Recent developments indicate a higher level of readiness, and it may be feasible to implement PATH earlier than thought

Impact of LIDAR Winds on FVGCM Forecasts

Average of 6 Ten–Day Forecasts

500 MB GEOPOTENTIAL HEIGHTS – N. HEM. EXTRA TROPICS

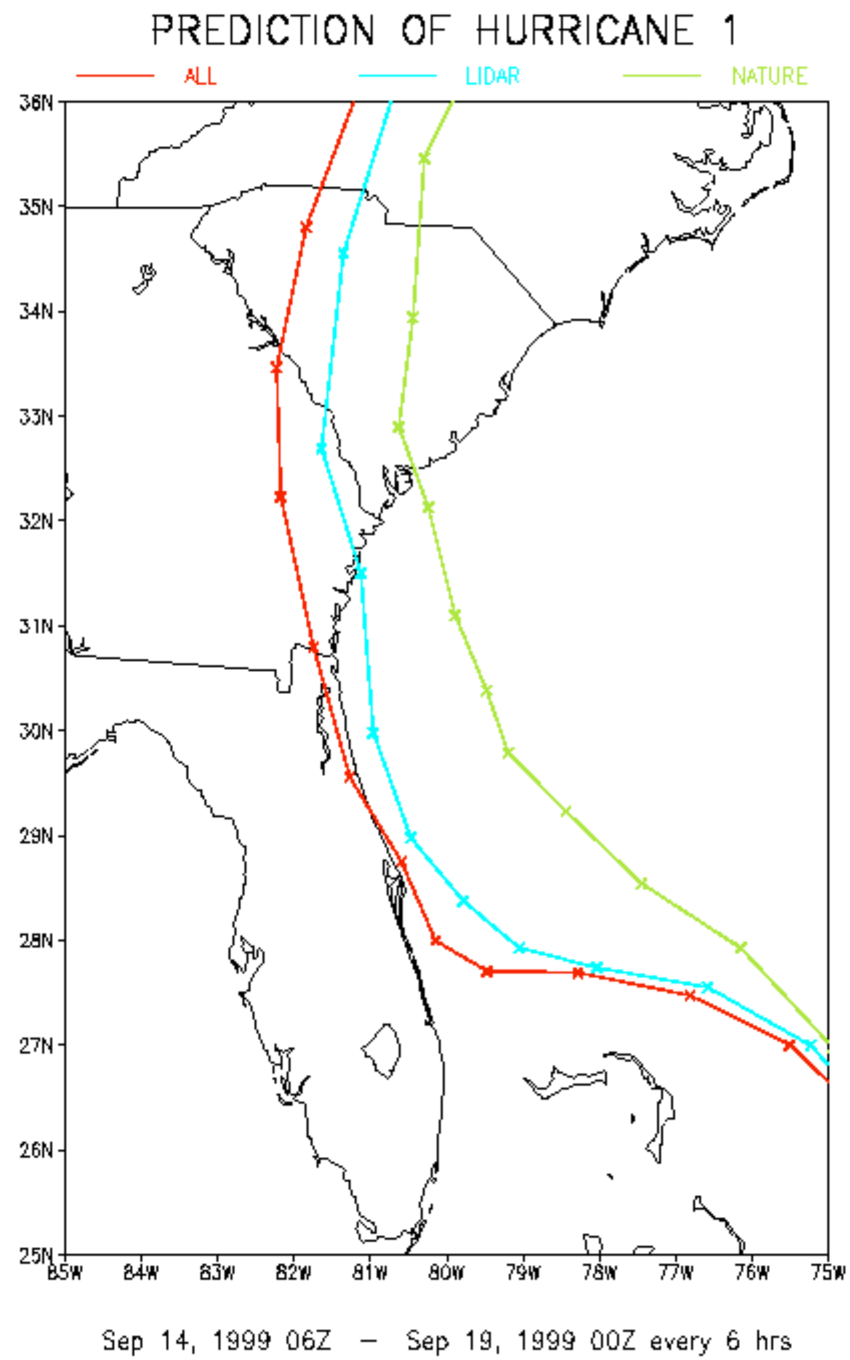
LAT : 30 N – 86 N LONG : 0 – 355 E



Doppler Wind Lidar Impact on Hurricane Prediction

Based on OSSE's conducted by NASA/GLA and NOAA/AOML in collaboration.

- Hurricane forecast tracks improved when adding simulated Doppler wind lidar observations (blue)
  - 100 km spacing
  - 25 km target sample volume
  - 1 m/s accuracy



Summary

1. Quantitative satellite data has been making important contributions to numerical weather prediction since the late 1970's.

2. It has contributed to improved initial conditions as well as to the development of improved models and data assimilation systems.

3. Results from the NASA and NOAA OSSEs that were conducted over the past twenty years using four different data assimilation systems, all indicate that there would be a substantial impact of space-based lidar winds on weather prediction provided that sufficient coverage and accuracy are achieved.

4. The need for higher temporal and spatial resolution suggest that ARIES, PATH, and XOVWM or Dual Frequency Scatterometer data have great potential to improve weather prediction beyond its current state.